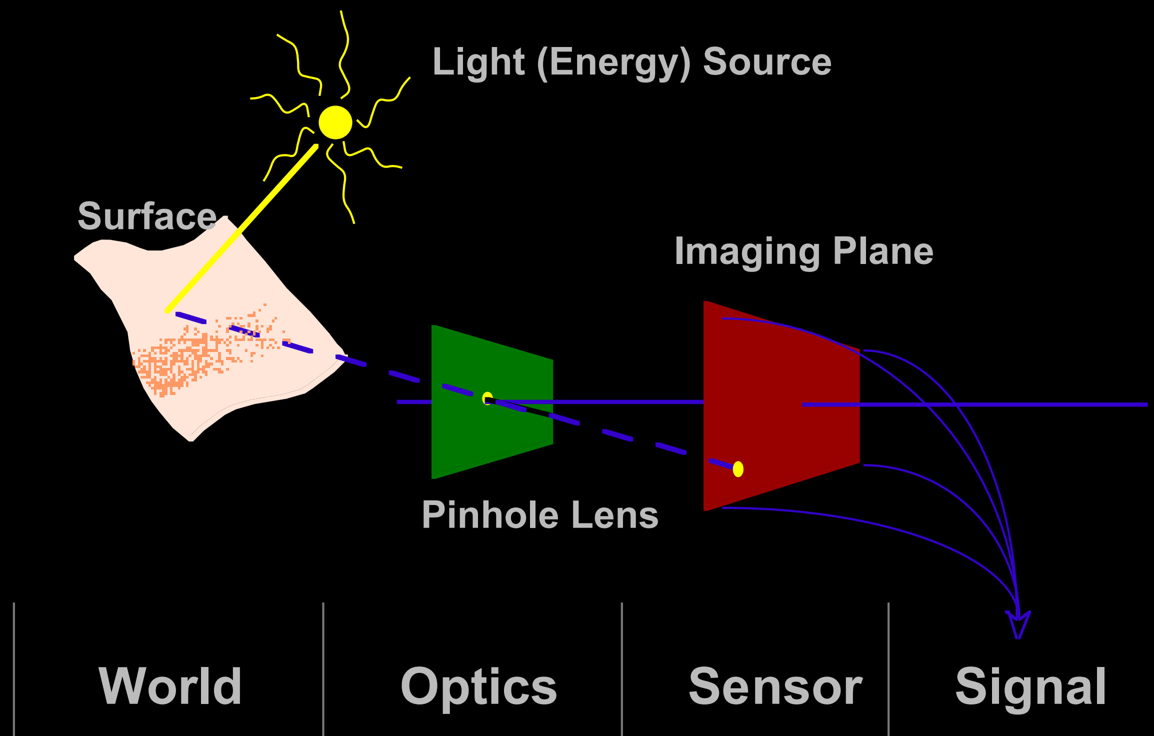
Image Formation



Sensor	Signal
B&W Film	Silver Density
Color Film	Silver density in three color layers
TV Camera	Electrical

Today and Next Lecture

- EM spectrum and visible light
- Distribution of light wavelengths
- Linearity
- Percent of light reflected off a surface.
  - Linearity of reflected light.
- Efficiency of a solar panel as a function of wavelength
  - Linearity of solar panel power.
- Photoreceptor response as a function of wavelength
  - Linearity of photoreceptor output.

If a tree falls in a forest

- If a tree falls in a forest, and there is no one there to hear it, does it make a sound?

If a tree falls in a forest

- If a tree falls in a forest, and there is no one there to hear it, does it make a sound?
  - Definition 1: Sound as a disturbance in a medium.
    - Answer: yes, there is a disturbance, and we can measure it.
  - Definition 2: Sound as a perception by people (or other creatures).
    - Answer: no, there is no perception.

Light

- Two very different, but related, subjects:
  - The physics of light.
  - The perception of light.

Simplifying Assumptions

- Typical imaging scenario:
  - visible light
  - ideal lenses
  - standard sensor (e.g. TV camera)
  - opaque objects
- Goal

> To create 'digital' images which can be processed to recover some of the characteristics of the 3D world which was imaged.

Steps

World ➡ Optics ➡ Sensor ➡
Signal ➡ Digitizer ➡
Digital Representation

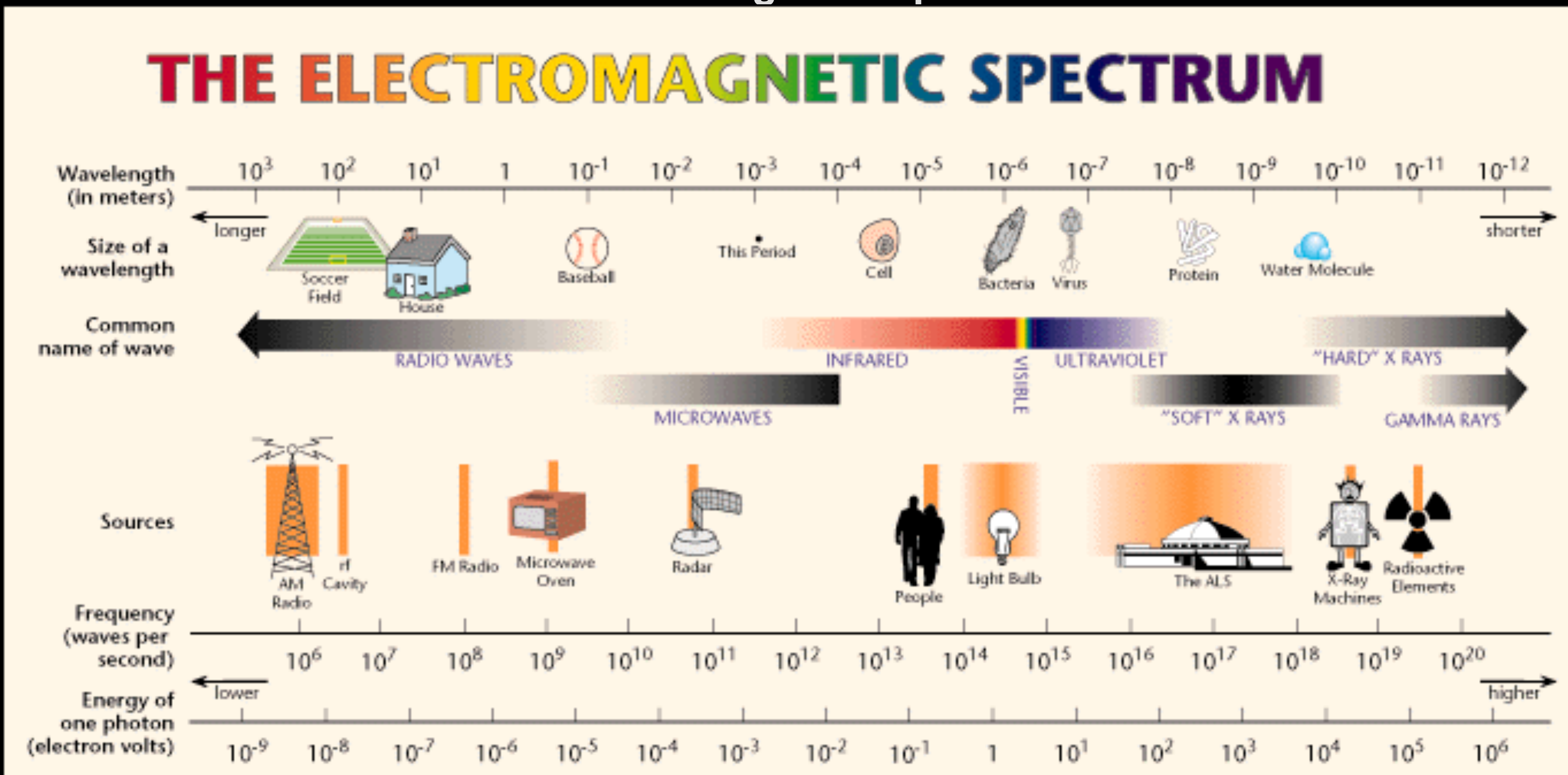
World	reality
Optics	focus {light} from world on sensor
Sensor	converts {light} to {electrical energy}
Signal	representation of incident light as continuous electrical energy
Digitizer	converts continuous signal to discrete signal
Digital Rep.	final representation of reality in computer memory

Light and Absorption

- What is the structure of light?
- What kind of light is relevant for
  - human vision?
  - animal vision?
  - computer vision?

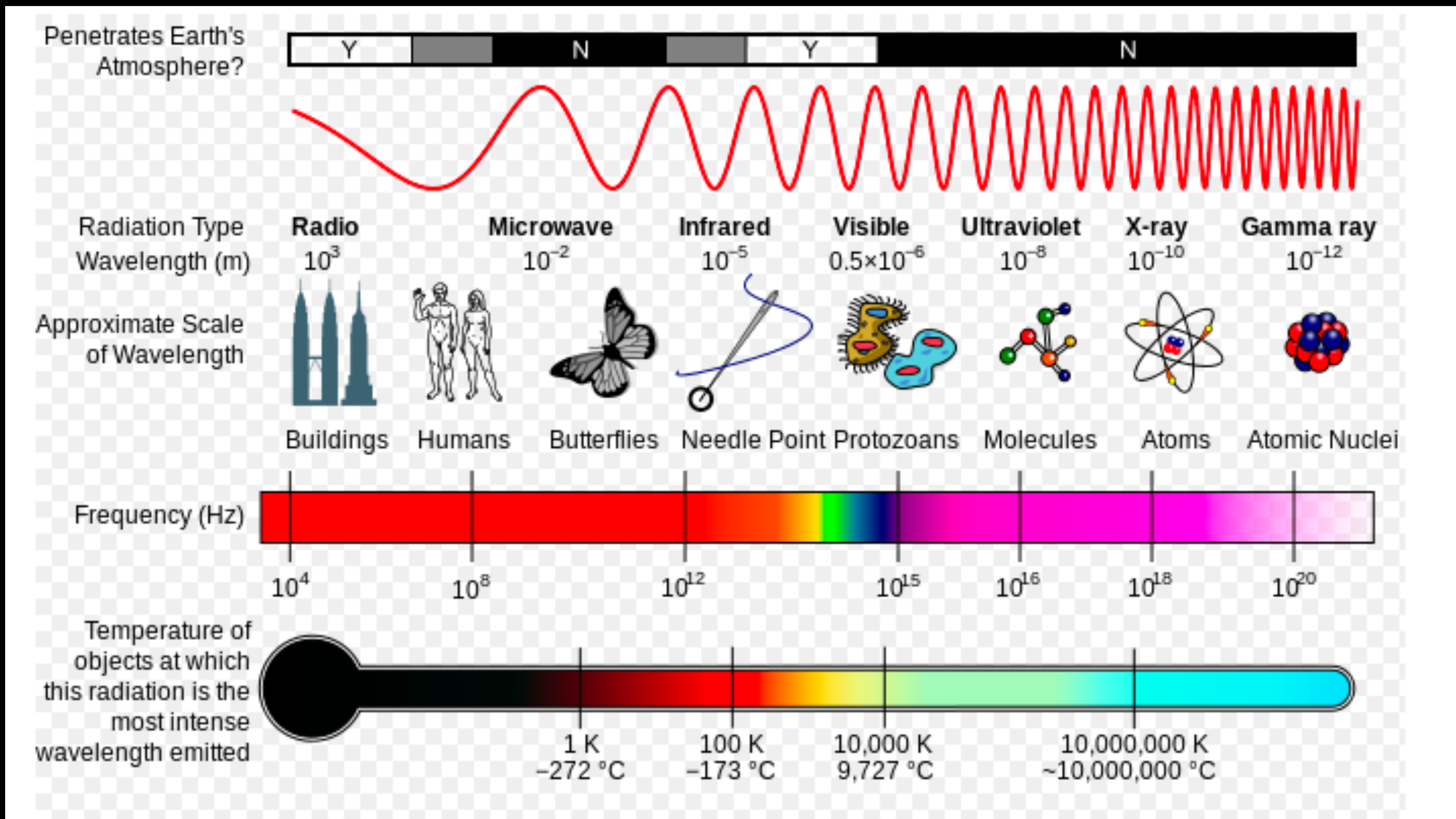
Light: EM Spectrum

Electromagnetic Spectrum



http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html

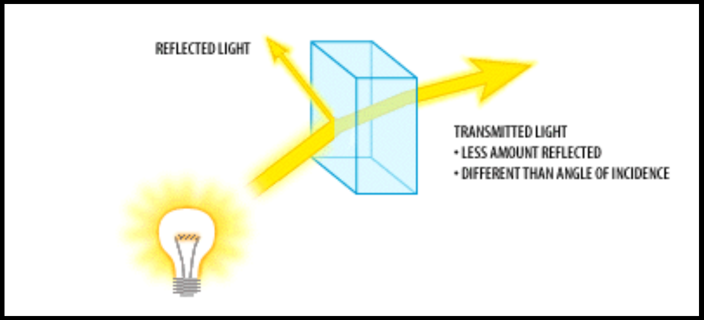
EM Spectrum

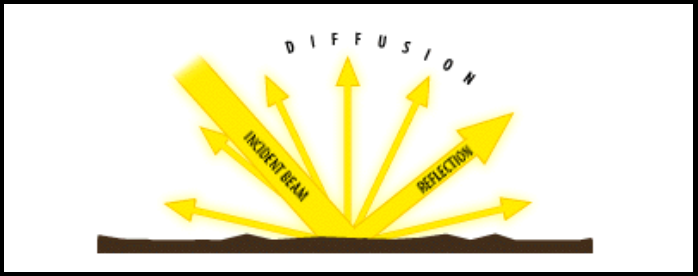


http://commons.wikimedia.org/wiki/File:EM_Spectrum_Properties_edit.svg

Interaction of Light and Matter

- When light strikes an object,
  - It will be wholly or partly transmitted.
  - It will be wholly or partly reflected.
  - It will be wholly or partly absorbed.
  - Physical surface properties dictate what happens





- When we see an object as blue or red or purple,
  - what we're really seeing is a partial reflection of light from that object.
  - The color we see is what's left of the spectrum after part of it is absorbed by the object.

Facts

- Visible wavelengths: 380-780 nanometers.
- Nanometer: 10^-9 meters.
- From shortest to longest:
  - gamma, X-ray, ultraviolet, visible, infrared, radar, FM radio, TV, shortwave (radio), AM radio

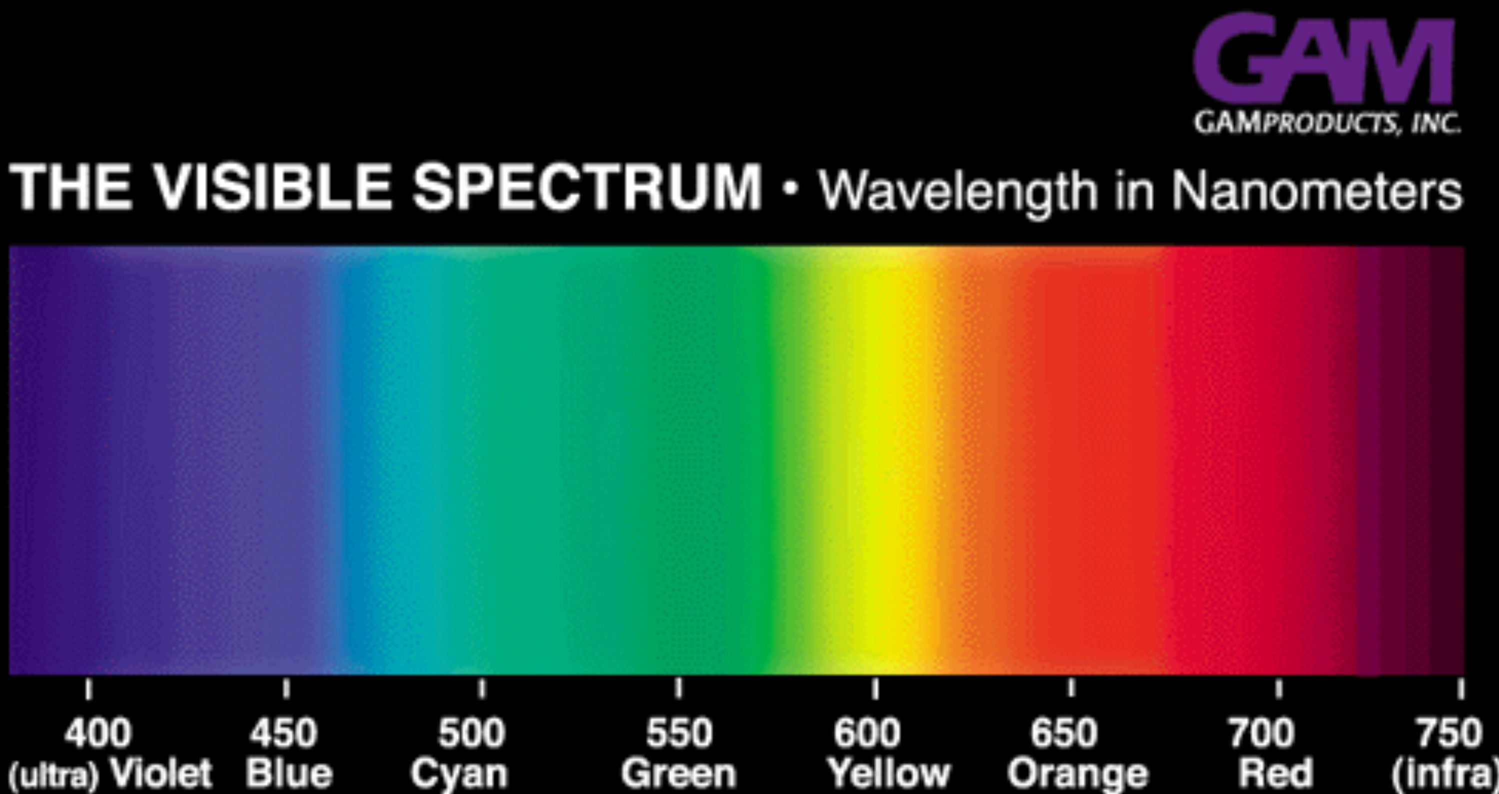
Visible Light

- Why do we see the visible spectrum and not other frequencies of light?
  - *Rhodopsins, photopsins, melanopsins* the biological chemicals that transduce light in humans, only respond at these wavelengths.

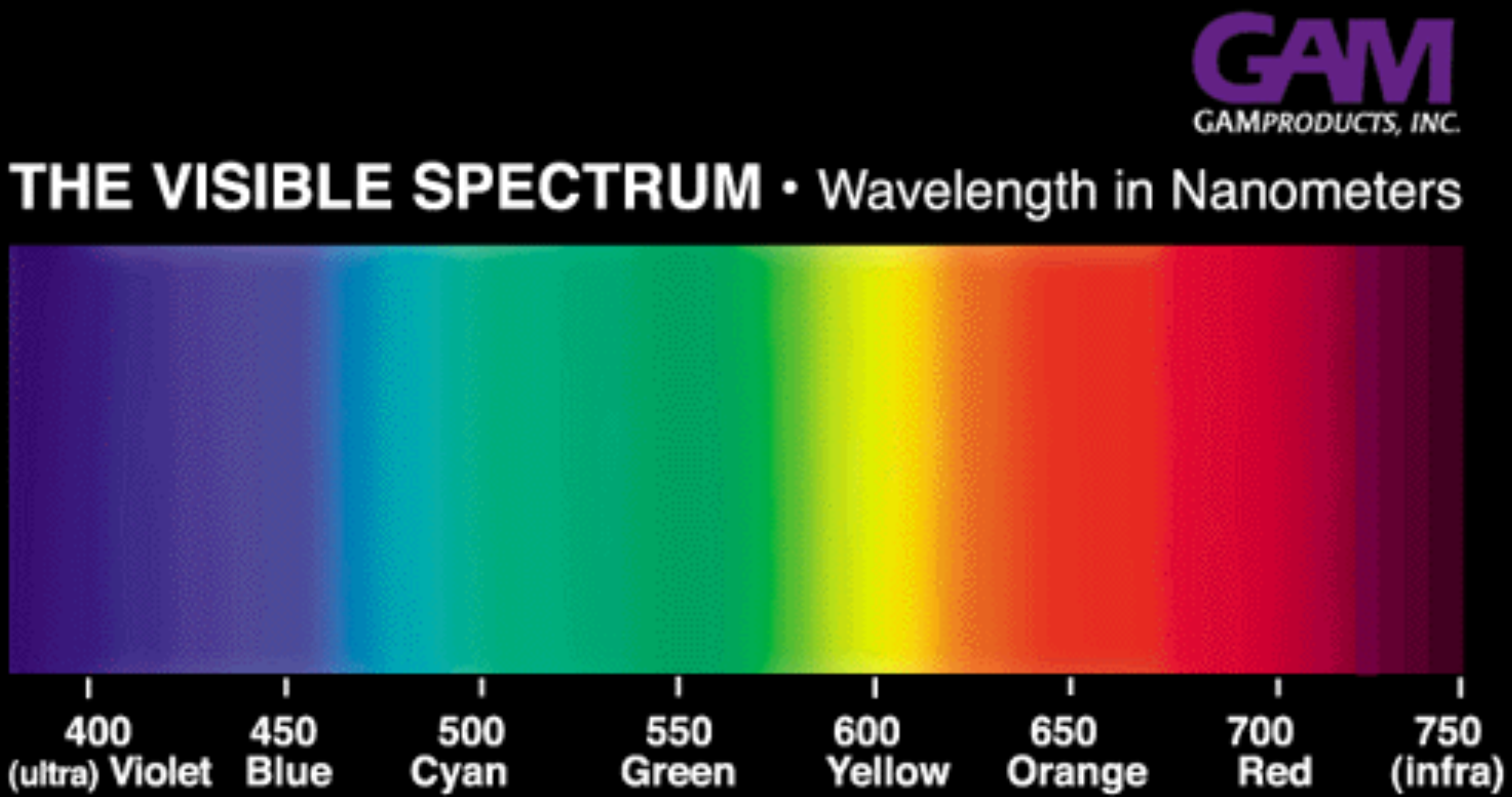
Spectrum Facts

- Higher energies (e.g. X-rays) harder to refract
  - Can’t be practically used with lenses.
- Not all animals are sensitive to the same spectrum:
  - Example: Bees see some ultraviolet
- More than one way to sense light:
  - Feel it instead of seeing it.

The visible spectrum

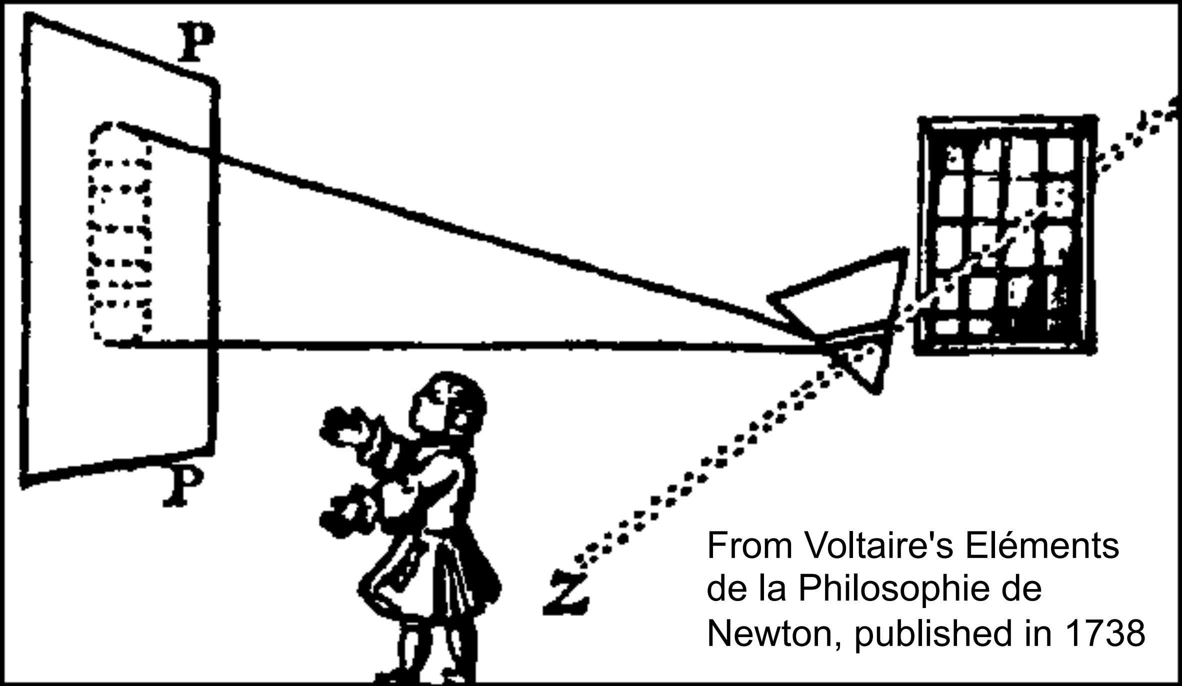


The visible spectrum



Where's white? Where's brown? Where's pink?

Newton 1666



From Voltaire's Eléments de la Philosophie de Newton, published in 1738

Composition of Natural Lights

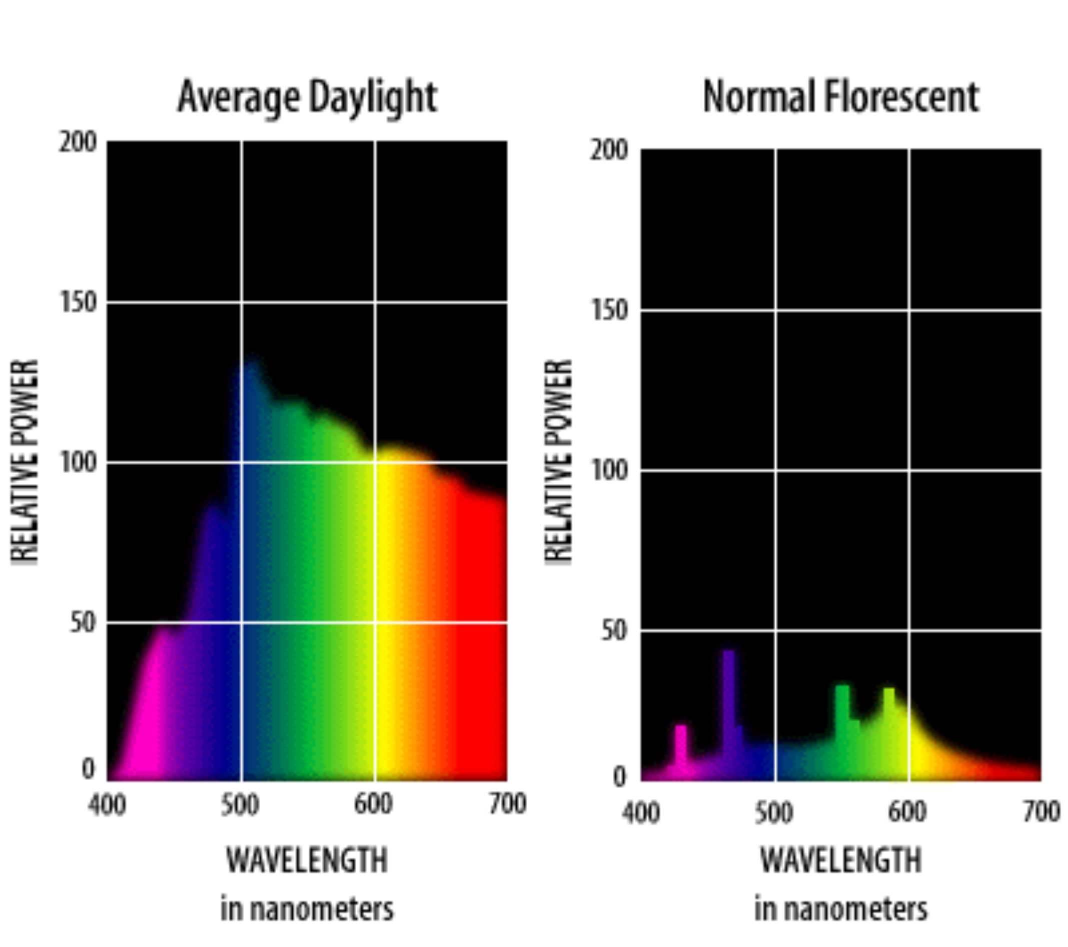
- Most light that you see has a large distribution of frequencies.
  - These multiple frequencies may appear together to form a single color of the spectrum:
    - red, blue, green, yellow
  - Or, they may appear to form a color that is not in the spectrum
    - White, brown, pink, magenta
- Why?
  - Before we get to that, we will explore the distribution of light in the world, and how it is transmitted, absorbed, etc.

Physics and Perception

- Usually, there is a large spectrum of wavelengths present
- Perception:
  - We perceive a single color of light (for each pixel).
- Perception and physics are not the same thing!

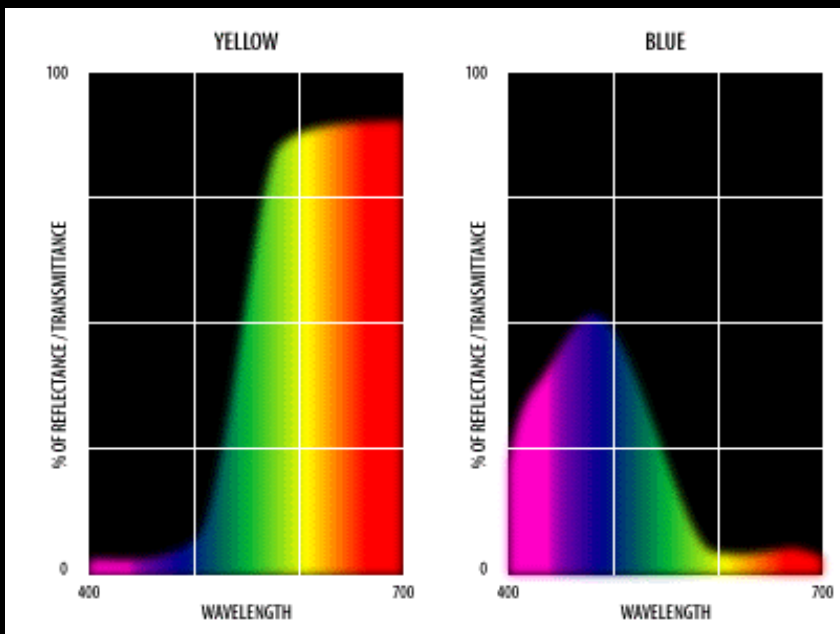
Spectral Distributions

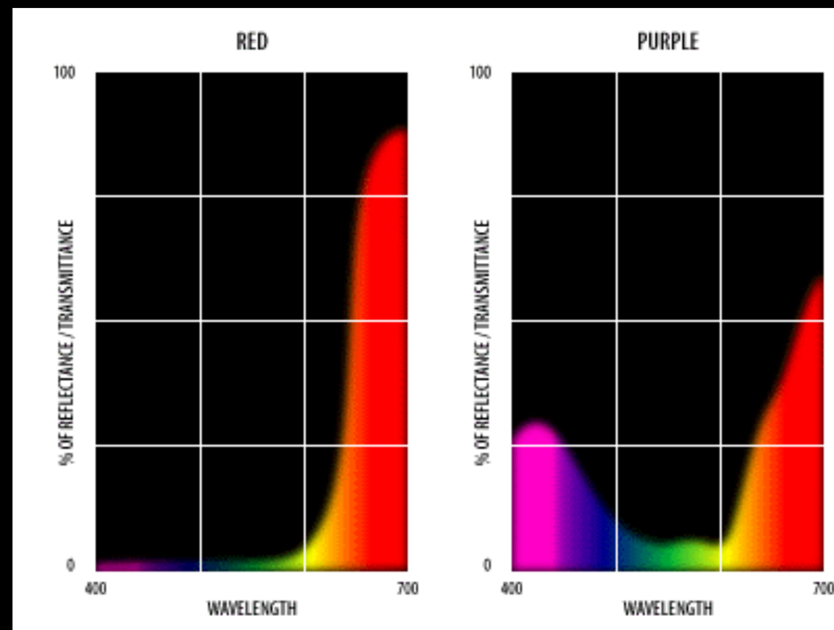
- Spectral distributions show the ‘amount’ of energy at each wavelength for a light source; e.g.



Spectral Reflectance Curves

- Reflectance curves for objects that appear to be:





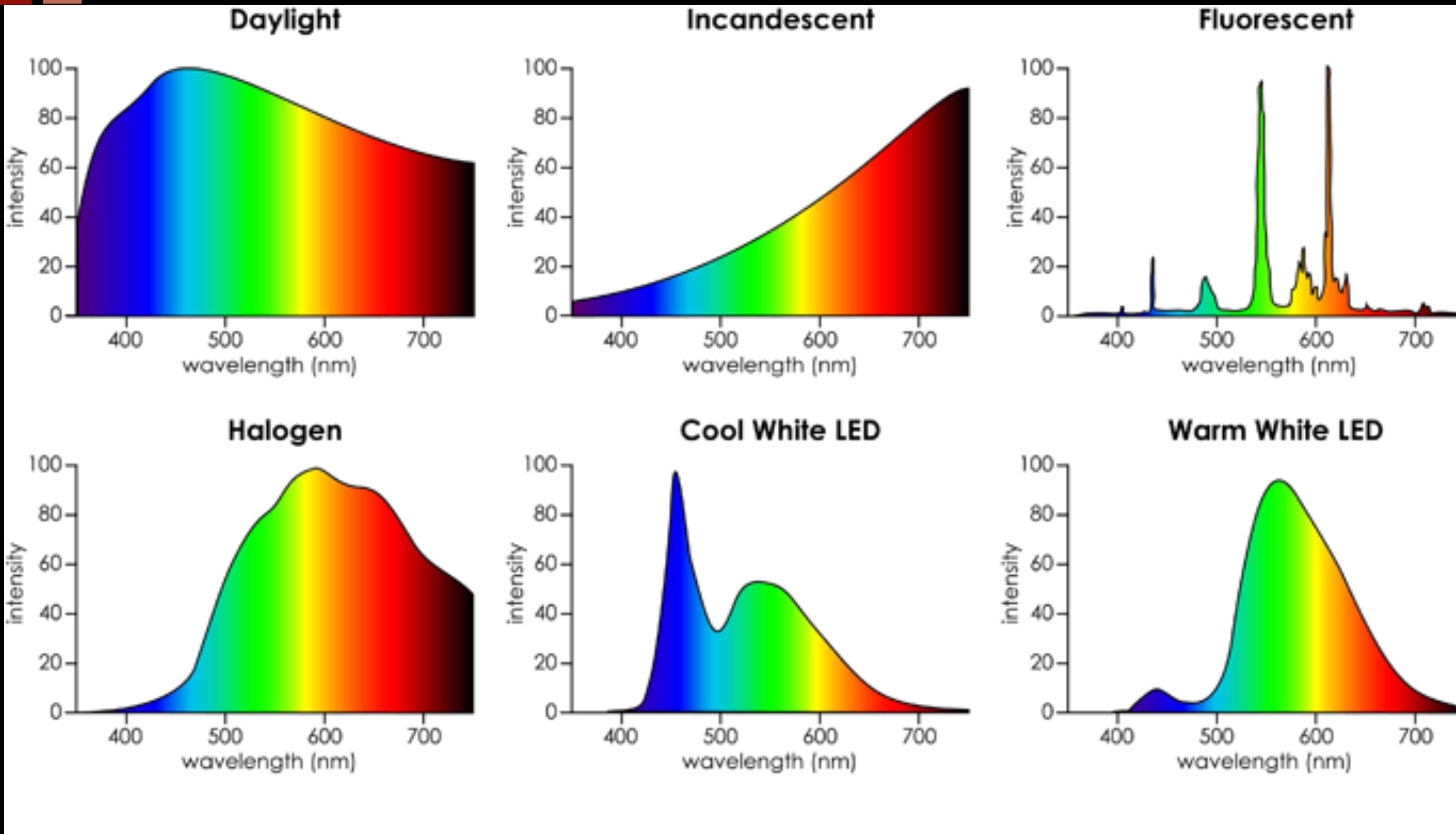
The wavelengths reflected or transmitted from or through an object determine the stimulus to the retina that provokes the optical nerve into sending responses to our brains that indicate color.

A Word about Units

- What are the units of relative power?
- For now, think of a standard setup:
  - One square meter light detector.
  - How many watts of power are landing on the light detector for each wavelength of the spectrum?
  - (watts per square meter per unit wavelength)

Light Bulb Spectra

Light bulbs



http://housecraft.ca/2012/09/30/the-diy-decorator’s-eco-friendly-lighting-dilemma/

Linearity

- A function f(x) is linear if and only if:
  - f(a)+f(b) = f(a+b), for all a and b.

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  - f(a)+f(b) = f(a+b), for all a and b.

- Corollary: for a linear function,
  - 2*f(a) = f(a)+f(a) = f(a+a) = f(2*a)

- “If you double the input, you double the output.”

Linearity of Light

- Double the intensity of sunlight
  - Double the output of a solar panel
- Double the duration of sunlight collection
  - Double the output of a solar panel
- Double the number of lightbulbs in a room
  - Double the number of photons coming off of each surface
- Double the amount of light coming into the eye.
  - Double the response of the rod and cone cells (the eye's photoreceptors)

Linearity

- Are these functions linear?
  - $f(x) = 2x+3$
  - $f(z) = 45z$
  - $f(y) = 3y^2$

  - $f(x) = Ax$, where A is a matrix and x is a vector
  - $g(x) = Ax+y$, where A is a matrix, x and y are vectors.

Light reflection

- Surface absorbs a percentage of light for each wavelength

Solar panels

- Linearity of solar panel responses:
  - Because the response of solar panels to light is approximately linear, we can calculate their total response as a sum of the responses to “individual” wavelengths:

Sensitivity of receptors

- Light receptors (biological and artificial) have different sensitivity to different wavelengths

- End